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Real-time augmentation of USDA yield grade application to beef carcasses using video image analysis[1,2]

R. Steiner*[3], A. M. Wyle†, D. J. Vote*, K. E. Belk*[4], J. A. Scanga*, J. W. Wise‡, J. D. Tatum*, and G. C. Smith*

*Department of Animal Sciences, Colorado State University, Fort Collins 80523-1171;
†Research Management Systems, Inc., Fort Collins, CO 80526;
and ‡USDA Agricultural Marketing Service, Livestock and Seed Program,
Livestock and Meat Standardization Branch, Washington, DC 20090-6456

ABSTRACT: In two phases, this study assessed the ability of two video image analysis (VIA) instruments, VIASCAN and Computer Vision System (CVS), to augment assignment of yield grades (YG) to beef carcasses to 0.1 of a YG at commercial packing plant speeds and to test cutout prediction accuracy of a YG augmentation system that used a prototype augmentation touch-panel grading display (designed to operate commercially in real-time). In Phase I, beef carcasses (n = 505) were circulated twice at commercial chain speeds (340 carcasses per hour) by 12 on-line USDA graders. During the first pass, on-line graders assigned a whole-number YG and a quality grade (QG) to carcasses as they would normally. During the second pass, on-line graders assigned only adjusted preliminary yield grades (APYG) and QG to carcasses, whereas the two VIA instruments measured the longissimus muscle area (LMA) of each carcass. Kidney, pelvic, and heart fat (KPH) was removed and weighed to allow computation of actual KPH percentage. Those traits were compared to the expert YG and expert YG factors. On-line USDA graders' APYG were closely related (r = 0.83) to expert APYG. Instrument-measured LMA were closely related (r = 0.88 and 0.94; mean absolute error = 0.3 and 0.2 YG units, for VIASCAN and CVS, respectively) to expert LMA. When YG were augmented using instrument-measured LMA and computed either including or neglecting actual KPH percentage, YG were closely related (r = 0.93 and 0.92, mean absolute error = 0.32 and 0.40 YG units, respectively, using VIASCAN-measured LMA; r = 0.95 and 0.94, mean absolute error = 0.24 and 0.34 YG units, respectively, using CVS-measured LMA) to expert YG. In Phase II, augmented YG were assigned (0.1 of a YG) to beef carcasses (n = 290) at commercial chain speeds using VIASCAN and CVS to determine LMA, whereas APYG and QG were determined by on-line graders via a touch-panel display. On-line grader YG (whole-number), expert grader YG (to the nearest 0.1 of a YG), and VIASCAN- and CVS-augmented YG (to the nearest 0.1 of a YG) accounted for 55, 71, 60, and 63% of the variation in fabricated yields of closely trimmed subprimals, respectively, suggesting that VIA systems can operate at current plant speeds and effectively augment official USDA application of YG to beef carcasses.

Key Words: Augmentation, Beef, Carcass Grading, Carcass Yield, Image Analysis

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Introduction

Assignment of USDA yield grades (**YG**) to beef carcasses by trained evaluators allowed ample time to measure and precisely determine YG factors accurately estimated beef carcass composition, accounting for 70 to greater than 80% of the variation in beef carcass cutability (Abraham et al., 1980; Cannell et al., 1999). However, because beef carcasses are presented to USDA graders at line-speeds of 200 to 450 carcasses per hour, more precise YG assignment using traditional grading techniques is not feasible.

Belk et al. (1996) proposed the idea of augmenting the application of YG using video image analysis (**VIA**) systems. The concept envisioned by Belk et al. (1996) would allow USDA graders to provide input that is not currently reproducible with an instrument, such as adjusted preliminary yield grade (**APYG**), while

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[3]Present address: Excel Corp., Wichita, KS 67219-7550.

[4]Correspondence: 7C Animal Science Bldg. (phone: 970-491-5826; fax: 970-491-0278; E-mail: Keith.Belk@colostate.edu).

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allowing an instrument to provide information, such as the longissimus muscle area (**LMA**), which cannot be evaluated accurately by graders at chain speeds, and to make the time-sensitive computations required to calculate a YG to the nearest 0.1 of a YG.

The objectives of this study were to ascertain if the accuracy of YG placement by USDA graders at chain speeds can be improved using instrument (Computer Vision System [**CVS**, Research Management Systems, USA Inc., Fort Collins, CO] or VIASCAN [VQA, Inc., Beenleigh, QLD, Australia]) augmentation when compared with traditionally determined on-line USDA or expert YG and to evaluate accuracy and precision of predicted cutout yields when YG are assigned to the nearest 0.1 of a YG unit and applied via an on-line, real-time instrument-augmented YG system.

Materials and Methods

This study was conducted in two phases (I and II) to evaluate the ability of two VIA systems to augment official, commercial application of USDA YG standards (USDA, 1997) to beef carcasses at commercial chain speeds. The two VIA systems evaluated in this study included the CVS and the VIASCAN Chiller Assessment System. Both commercial VIA systems rely on digital imaging technology, combined with proprietary image segmentation and analysis software, to evaluate cross sections of the longissimus muscle (**LM**) of beef carcasses at the 12th/13th rib interface (the "ribeye"). Specifically, in this study, these two VIA systems were used to determine LMA (cm^2).

Phase I

Phase I of this study was designed such that the improvement in YG assignment accuracy using instrument augmentation systems, compared with expert (group of experts) and traditional on-line USDA grader YG, could be evaluated with respect to two separate methods for computing final augmented YG. Although all final YG assigned to carcasses were computed using the USDA "short-cut" method (Savell et al., 1998), the two final augmented YG computation methods used in this study differed with regard to how short-cut YG adjustment factors were derived to compute the final augmented YG. Method 1 for computing augmented final YG included the following USDA on-line grader APYG; actual (removed and weighed) percentage of kidney, pelvic, and heart fat (**KPH**); VIA (separate yield grades were computed using output from each of the CVS and VIASCAN systems) measurements of the LM; and hot carcass weight (**HCW**). Method 2 for computing final augmented YG differed from Method 1 only in that a standardized KPH adjustment factor (the overall sample mean of –0.3 YG units) was used in the computation of final augmented YG rather than actual (removed and weighed) KPH.

Steer and heifer carcasses (n = 505) were selected from a commercial packing plant (ConAgra Beef Co., Greeley, CO) grading chain (252 carcasses during the first week and 253 carcasses during the second week of Phase I) by personnel of USDA and Colorado State University (CSU). Excluded from selection were improperly ribbed carcasses, carcasses exhibiting bruises and/or other defects that affected the surface area of the LM, and carcasses otherwise not eligible to be graded. Carcasses were selected to represent all extremes associated with both cutability and quality determining characteristics.

Carcasses selected for inclusion in the study were placed on stationary rails in the holding cooler, where an expert panel of USDA Agricultural Marketing Service beef graders were provided ample time and access to all carcasses to determine expert grade factors for each carcass, including preliminary YG (**PYG**), APYG, KPH, HCW, overall maturity, marbling score, and LMA (determined by using the plastic grid method). Expert YG and quality grade (**QG**) were then calculated using these factors.

Following determination of expert YG factors, carcasses were circulated past the grading stand at commercial production speeds (340 carcasses per hour), to a group of four to six USDA on-line graders at a time (up to three circulations so that a total of 12 on-line graders assigned grades). On-line graders assigned a YG and QG to each carcass, but carcasses were not marked with grade insignia.

Colorado State University personnel recorded grades to prevent communication among on-line graders so that their estimates of final YG and QG were completely independent of each other. At the completion of the first presentation to on-line graders of carcasses past the grading stand, carcasses were presented to the same graders a second time. The second time, USDA on-line graders assigned APYG and QG to each carcass, as they would in an instrument augmentation system, and researchers recorded the QG and APYG assigned to each carcass by each individual grader, resulting in 5,696 comparisons to the expert grades. Simultaneously, the CVS and VIASCAN systems recorded an image of the LM of both sides of each carcass in real-time each time a carcass was circulated past the grading stand. These measurements were subsequently used to compute final augmented YG.

Carcasses were then transferred back to stationary rails in the holding cooler, where KPH fat was completely removed from each carcass by CSU personnel, and weighed in order to determine the actual KPH percentage. The removal of KPH was to simulate possible removal on the harvest floor and the subsequent use of actual KPH percentage in an augmented YG assignment system.

Statistical Analyses. Descriptive statistics and simple correlation coefficients were calculated using SAS (SAS Inst., Inc., Cary, NC). Instrument LMA measurements were regressed on expert LMA measurements

Table 1. Numbers of carcass sides utilized in Phase II (n = 146 right and 144 left sides), by sex-class, weight class, and final expert yield grade

	Steers		Heifers		
Yield grade[a]	Light[b]	Heavy[c]	Light[b]	Heavy[c]	Row totals
1	6	6	10	3	25
2A	10	14	7	11	42
2B	13	17	14	18	62
3A	11	13	25	18	67
3B	5	18	20	8	51
4 and 5	3	14	15	11	43
Column totals	48	82	91	69	290

[a]Yield grade: Final computed expert yield grade such that 1 = ≤ 1.9; 2A = 2.0 to 2.4; 2B = 2.5 to 2.9; 3A = 3.0 to 3.4; 3B = 3.5 to 3.9; 4 and 5 = ≥ 4.0.
[b]Light = 249.5 to 339.7 kg.
[c]Heavy = 340.2 to 458.1 kg.

using the PROC REG procedures of SAS in order to account for the mean differences that occurred between the VIA methods of measuring LMA and the plastic grid method of measuring LMA. The mean absolute difference between these adjusted VIA LMA measurements and the expert LMA measurements were calculated. Also, mean absolute differences between on-line grader APYG and expert grader APYG were calculated. Expert YG (calculated to the nearest 0.1 using actual KPH percentages) were regressed on on-line grader whole-number YG and YG calculated using combinations of expert YG factors, on-line grader YG factors, actual or standardized (2%) KPH, and CVS- or VIASCAN-measured LMA.

Phase II

Phase II of this study tested the cutting yield prediction accuracy of YG assigned by instrument augmentation using a full hardware system (CVS and VIASCAN systems equipped with a prototype augmentation touch-panel grading display, designed to operate commercially in real-time), for USDA on-line grader input and in-line identification. During a 5-wk period, steer and heifer carcasses (n = 290) were selected from the grading chain prior to circulation past the grading stand in a commercial packing plant (ConAgra Beef Co.) by CSU personnel to fill a 2 × 6 × 2 design matrix reflecting differences in sex-class, YG, and HCW (Table 1).

Following selection, carcasses were circulated past the grading stand twice in a random sequence at commercial production speeds (340 carcasses per hour). During each of the two circulations, one of the two VIA systems (CVS or VIASCAN) was installed in connection with the prototype augmentation touch-panel grading display that was used by the USDA on-line graders to input APYG, as well as to view all other carcass YG factors. The VIA camera head unit during each circulation was positioned on the grading stand in front of the on-line USDA grader. As data from each carcass was inputted via the camera head unit, transmission to the augmentation touch-panel was timed so that the grade information displayed on the touch-panel reflected the carcass that was passing by the on-line grader's position on the chain at that point in time. In wk 1, 2, and 5 of data collection, the CVS was used during the first circulation of carcasses past the grading stand, and the VIASCAN system was used during the second circulation. In wk 3 and 4, VIA system alternation occurred in reverse order.

Video image analysis systems recorded an image of the LM on the leading side of each carcass and determined LMA and PYG, whereas actual KPH percentage (based on chilled side weight) was used to compute the final, augmented YG. A bar code reader allowed the downloading of HCW and carcass identification data to the touch panel. Once the USDA line-grader adjusted the PYG and entered the QG, a computer system that assimilated inputs from the VIA instrument and the touch-panel calculated the final augmented YG to the nearest 0.1 of a YG.

Following on-line grade assignment using instrument augmentation, a panel of expert USDA graders determined expert values for PYG and adjusted PYG (for each side), overall maturity, marbling score, and LMA (plastic grid method). Expert YG for the sides fabricated were calculated using these factors in addition to the actual KPH.

Colorado State University personnel then selected the right or left side of each carcass (balancing the numbers of right or left sides selected) for fabrication. A crew of experienced plant meat-cutters, under the supervision of CSU personnel, fabricated each side into boneless, closely trimmed (0.64 cm of external fat) subprimal cuts according to the following NAMP 1997 specifications: chuck eye roll (NAMP 116A); clod (NAMP 114); chuck tender (NAMP 116B); lip-on ribeye roll (NAMP 112A); striploin (NAMP 180); top sirloin butt (NAMP 184); peeled tenderloin (NAMP 189A); inside round (NAMP 168); bottom round flat (NAMP 171B); bottom round eye (NAMP 171C); and peeled knuckle (NAMP 167A).

Table 2. Expert grader means, standard deviation, and minimum and maximum values obtained for carcasses sampled (n = 505) in Phase I

Trait	Mean	SD	Minimum	Maximum
Overall maturity[a]	63	11	50	140
Marbling score[b]	394	65	270	740
Preliminary yield grade	3.0	0.5	2.0	4.8
Adjusted preliminary yield grade	3.3	0.5	2.0	4.5
Kidney, pelvic, and heart fat, %[c]	2.1	0.6	0.5	4.0
Longissimus muscle area, cm^2 [d]	93.6	11.6	60.7	131.0
Hot carcass weight, kg	360.7	39.9	245.3	470.4
Expert yield grade	2.8	0.9	1.0	5.0

[a]Composite of lean and skeletal maturity: 0 to 99 = A-maturity; 100 to 199 = B-maturity.
[b]Expert marbling score: 200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small; 500 to 599 = Modest; 600 to 699 = Moderate; and 700 to 799 = Slightly abundant.
[c]Kidney, pelvic, and heart fat estimated as a percentage of hot carcass weight.
[d]Measured using the plastic grid method.

Preparation for cutability tests included separation of the forequarter and hindquarter between the 12th and 13th ribs, weighing of the forequarter and hindquarter individually, and summing those weights to determine initial chilled side weights. As carcasses were fabricated, weights of subprimals, fat, bone, and lean trimmings were recorded for each side. Carcasses for which the sum of weights for all components failed to meet a 99.5% (of chilled side weight) recovery criterion were excluded from the study (a total of 12 sides were discarded from this phase).

Statistical Analyses. Descriptive statistics and simple correlation coefficients were calculated using SAS. Subprimal cut yield percentage, fat percentage, and bone percentage were regressed on on-line grader whole-number YG, expert grader whole-number YG, expert grader YG calculated to the nearest 0.1, and VIA augmented YG calculated to the nearest 0.1.

Results and Discussion

Phase I

Descriptive statistical information for carcasses sampled is provided in Table 2. It was apparent that the carcasses sampled in this study closely reflected the national consist according to the National Beef Quality Audit—2000 (McKenna et al., 2002).

Whole-number YG, assigned by on-line graders, were moderately correlated (r = 0.77, mean absolute error = 0.38 ± 0.51 YG units) to expert whole number YG, suggesting that there was room for augmentation to improve accuracy of YG assignment to beef carcasses (data not presented in tabular form). Simple correlations between line-grader APYG and expert APYG measurements (r = 0.83, mean absolute error = 0.23 ± 0.21 YG units) indicated that on-line graders were capable of accurately assigning APYG to beef carcasses in real-time (data not presented in tabular form). Additionally, simple correlation coefficients between VIA-measured LMA and expert LMA were high (r = 0.88 and r = 0.94, mean absolute error = 0.30 and 0.20 YG units for the VIASCAN and CVS systems, respectively; data not presented in tabular form). Because Belk et al. (1998) demonstrated that LMA was the YG factor that held the most promise for measuring with an instrument in an augmentation system, it appeared that VIA technology would be a viable tool for accurately measuring LMA of beef carcasses in an on-line augmentation system.

Coefficients of determination (R^2) and residual SD values for the augmented vs. expert final YG are presented in Table 3. Yield grade augmentation systems using expert APYG, actual KPH percentage, actual HCW, and VIA-measured LMA accounted for 90 to 95% of the variation in expert YG. When expert APYG was replaced with USDA line-grader APYG, augmented final YG was still highly accurate and precise when compared to expert final YG.

Belk et al. (1998) and Cannell et al. (1999) found that on-line grader estimates of KPH percentage correlated only marginally (r = 0.66) with expert KPH percentages. Thus, for Phase I of this study, on-line USDA graders were not asked to estimate KPH percentages during the second pass of carcasses by the grading stand. Removal of the influence of variability in KPH percentage from the calculation of YG (accomplished by substituting the sample mean KPH percentage adjustment of minus 0.3 for each carcass in order to maintain numerical integrity) reduced accuracy of the augmented YG utilizing on-line USDA grader APYG and standardized KPH percentage in relation to expert final YG by only 1%. Yield grades calculated to 0.1 of a YG could be more accurately applied to beef carcasses with actual KPH percentage determined on the harvesting floor; nonetheless, use of a standardized value in the short-cut equation to account for the effect of KPH percentage is a viable alternative.

If a YG instrument augmentation system were to be implemented in the commercial setting, USDA on-line graders would only need to determine APYG for beef carcasses, rather than all factors that are used to determine final YG. Additionally, the on-line grader

Table 3. Coefficients of determination (R^2) and residual standard deviation (RSD) values for final yield grade determined by on-line USDA graders, or using Computer Vision System (CVS) or VIASCAN longissimus muscle area measurements in relation to final expert yield grade (Phase I)

Adjustment factors included in the short-cut equation to compute final yield grade					
APYG[a]	LMA[b]	% KPH[c]	HCW[d]	R^2	RSD
On-line grader	On-line grader	Estimated	Actual	0.67	0.53
Expert	CVS	Actual	Actual	0.95	0.19
Expert	CVS	Standardized	Actual	0.95	0.21
On-line grader	CVS	Actual	Actual	0.89	0.31
On-line grader	CVS	Standardized	Actual	0.88	0.31
Expert	VIASCAN	Actual	Actual	0.90	0.28
Expert	VIASCAN	Standardized	Actual	0.90	0.29
On-line grader	VIASCAN	Actual	Actual	0.81	0.40
On-line grader	VIASCAN	Standardized	Actual	0.81	0.40

[a]Adjusted preliminary yield grade.
[b]Longissimus muscle area.
[c]Kidney, pelvic, and heart fat percentage: Actual = weight of kidney, pelvic, and heart fat as a percentage of the cold side weight; Standardized = 2%; and Estimated = percentage of kidney, pelvic, and heart fat estimated by on-line USDA graders.
[d]Hot carcass weight.

would not be required to rapidly perform the calculations necessary to determine final YG. As a result, graders would be able to allocate more time to the accurate determination of APYG and quality traits, resulting in a more precise evaluation of carcass characteristics. Augmenting the application of YG by VIA technology improved YG placement accuracy, compared with traditional methods, and allowed assignment of YG to carcasses at chain speeds to 0.1 of a YG. This did not influence the accuracy of USDA online grader QG placement when compared with the expert QG (r = 0.69 and 0.69, for traditional and augmentation methods, respectively; data not presented in tabular form).

Phase II

Descriptive statistics for carcass characteristics, CVS and VIASCAN measurements for 290 sides of beef in the sample are presented in Table 4. The large SD for HCW, LMA, and marbling scores reflected selection of carcasses to fit the design to represent a broad range of differences likely to be encountered in the U.S. beef carcass population.

Simple correlation coefficients between expert YG factors and YG factors provided by USDA on-line graders, CVS, and VIASCAN are presented in Table 5. Results mirror those from Phase I, indicating that acceptable YG placement accuracy can be achieved using USDA on-line grader APYG and instrument measures of LMA to augment YG application. Trimming of external fat for ease of fabrication and removal of foreign material increases the need to adjust PYG; thus, it is difficult for a machine to accurately measure carcass fatness. In Phase II, 68% of carcasses required some PYG adjustment by the on-line grader to be entered into the augmentation touch panel grading display. This caused graders to spend more time looking at the touch-panel than the carcasses, resulting in less accurate assessments of carcass traits than when this system was simulated previously (Belk et al., 1998; Cannell et al., 1999). Mean absolute error (mean absolute difference from expert APYG) for APYG determined by USDA on-line graders was 0.10 ± 0.08 YG units, which was comparable to results presented by Murphey et al. (1983) and Belk et al. (1998). Given that external fat thickness is the most important factor in the USDA short-cut equation, use of highly accurate APYG (which can be accomplished by USDA online graders) is crucial in an augmentation system for improved YG placement.

As indicated in Table 5, CVS and VIASCAN measures of LMA were highly correlated with expert LMA measures. When LMA was measured using CVS or VIASCAN, mean absolute errors (from the expert LMA) of 0.20 ± 0.10 and 0.32 ± 0.20 YG units for CVS and VIASCAN, respectively, were attained. Based on these and previous results (Morgan-Jones et al., 1995; Borggaard et al., 1996; Cannell et al., 1999), it appears that VIA technology is a viable tool for accurately and precisely measuring LMA at commercial chainspeeds.

Simple correlation coefficients between expert final YG and final YG generated on-line and in real-time as a result of instrument augmentation using CVS and VIASCAN to measure LMA, and on-line USDA graders to determine APYG and to operate the touch panel were r = 0.90 and 0.86, respectively (Table 5). Additionally, mean absolute errors for augmented YG were 0.52 ± 0.55 and 0.43 ± 0.34 YG units for CVS and VIASCAN, respectively. These values were slightly different than results obtained in Phase I of this study because of differing samples of carcasses and the fact that on-line USDA graders in Phase II were also re-

Table 4. Descriptive statistics for expert, Computer Vision System (CVS), and VIASCAN measured carcass characteristics collected in Phase II for the sample population

Factors	Mean	SD	Minimum	Maximum
Actual hot carcass weight	343	41	255	458
Actual kidney, pelvic and heart fat, %	2.5	0.8	0.5	6.2
Expert marbling score[a]	426	98	270	730
Expert overall maturity[b]	62	12	40	130
Expert preliminary yield grade	3.1	0.6	2.0	5.2
Expert adjusted preliminary yield grade	3.4	0.6	2.3	5.8
Expert longissimus muscle area, cm^2	85.5	11.2	58.7	127.7
Expert final YG (to 0.1 of a YG)[c]	2.6	0.9	0.6	5.8
CVS preliminary yield grade	3.2	0.5	2.2	4.9
CVS longissimus muscle area, cm^2	87.4	12.5	59.6	127.8
CVS augmented final YG (to 0.1 of a YG)[d]	2.7	0.9	0.4	5.5
VIASCAN preliminary yield grade	3.2	0.6	2.0	4.9
VIASCAN longissimus muscle area, cm^2	82.1	14.0	53.0	125.5
VIASCAN augmented final YG (to 0.1 of a YG)[e]	3.0	1.0	0.8	5.9

[a]Expert marbling score: 200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small; 500 to 599 = Modest; 600 to 699 = Moderate; and 700 to 799 = Slightly abundant.

[b]Composite of lean and skeletal maturity: 0 to 99 = A-maturity; 100 to 199 = B-maturity.

[c]Expert yield grade (YG) calculated to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.

[d]Yield grade determined by augmentation using CVS to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.

[e]Yield grade determined by augmentation using VIASCAN to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.

quired to operate the prototype augmentation touch panel grading display. It is likely that use of the augmentation touch-panel by graders during Phase II may have introduced error due to inexperience with the system. However, both the CVS and VIASCAN augmentation systems still allowed YG to be assigned to beef carcasses to the nearest 0.1 of a YG at commercial chain speeds with higher levels of accuracy than USDA on-line graders currently are able to achieve. Further improvements to the augmentation touch panel grading display and grader experience would likely lead to higher accuracy levels.

A number of simple linear regression models were developed to predict carcass yield and used expert final YG, on-line grader whole-number YG, and CVS- and VIASCAN-augmented final YG as independent variables (Table 6). Final YG (calculated to the nearest 0.1 of a YG) that were augmented using CVS accounted for 63, 51, and 6% of the observed variability in subprimal, fat, and bone yields, respectively, whereas final

Table 5. Simple correlations (r) between on-line grader, expert grader, Computer Vision System (CVS) and VIASCAN determined yield grade factors for Phase II

	Expert factors and final yield grade			
	MPYG[a]	APYG[b]	LMA[c]	Final YG[d]
CVS MPYG	0.70	0.66	–0.18	0.62
On-line grader APYG	0.88	0.87	–0.20	0.79
CVS LMA	–0.28	–0.38	0.90	–0.62
CVS augmented YG[e]	0.77	0.79	–0.50	0.90
VIASCAN MPYG	0.87	0.82	–0.25	0.76
On-line grader APYG	0.87	0.87	–0.27	0.80
VIASCAN LMA	–0.26	–0.34	0.83	–0.57
VIASCAN augmented YG[f]	0.73	0.75	–0.53	0.86

[a]Measured preliminary yield grade.

[b]Adjusted preliminary yield grade.

[c]Longissimus muscle area measured using the plastic grid method.

[d]Final yield grade determined using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.

[e]Yield grade determined by augmentation using CVS to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.

[f]Yield grade (YG) determined by augmentation using VIASCAN to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.

All correlations differed from zero ($P < 0.001$).

Table 6. Coefficients of determination (R^2) and residual standard deviation (RSD) values for final yield grade determined by on-line USDA graders, expert graders, or augmented using Computer Vision System (CVS) or VIASCAN longissimus muscle area measurements in relation to actual cutout yields (Phase II)

	Subprimal cuts[a]		Fat[b]		Bone[c]	
Yield grades determination method	R^2	RSD	R^2	RSD	R^2	RSD
On-line graders to the whole grade[d]	0.55	0.013	0.56	0.020	0.17	0.010
Expert to the whole grade[ef]	0.62	0.012	0.58	0.018	0.10	0.010
Expert to 0.1 of a grade[f]	0.71	0.011	0.59	0.018	0.06	0.012
CVS augmentation to 0.1 of a grade[g]	0.63	0.012	0.51	0.022	0.06	0.012
VIASCAN augmentation to 0.1 of a grade[h]	0.60	0.013	0.46	0.023	0.04	0.013

[a]Subprimal cuts from the round, loin, rib, and chuck trimmed to 0.64 cm fat depth as a percentage of chilled side weight.
[b]Percentage of chilled side weight of fat from the production of subprimal cuts.
[c]Percentage of chilled side weight of bones removed during production of subprimal cuts.
[d]Whole yield grade as assigned by on-line USDA graders at chain speeds.
[e]Expert yield grade calculated to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication and converted to whole grade (<2.0 = 1, 2.0 to 2.9 = 2, 3.0 to 3.9 = 3, 4.0 to 4.9 = 4, and >5.0 = 5).
[f]Expert yield grade calculated to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.
[g]Yield grade determined by augmentation using CVS to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.
[h]Yield grade determined by augmentation using VIASCAN to 0.1 of a grade using actual KPH = percentage of chilled side weight of actual kidney, pelvic, and heart fat present at the time of fabrication.

YG, augmented using VIASCAN, accounted for 60, 46, and 4% of the observed variation in subprimal, fat, and bone yields, respectively. On-line graders' whole-number YG accounted for 55, 56, and 17% of the observed variation in subprimal, fat, and bone yields, respectively. The ability of USDA on-line graders to predict cutability in this study conflicted with results of previous researchers (Herring, et al., 1994; Cannell, et al., 1999; Walenciak, et al., 2000), where USDA on-line grader YG accounted for much lower proportions of observed variance relative to subprimal cutability prediction; however, results presented by Gardner et al. (1996) were analogous to those obtained during Phase II of this study. The predictive accuracy of CVS- and VIASCAN-augmented YG were only 8 to 11% less than the predictive accuracy of expert YG. Nonetheless, augmenting USDA on-line grader-assigned YG improved predictive accuracy (based on R^2 values) by approximately 5 to 8%.

The static tripod feature of the augmentation touch panel was a major impediment to the physical movement of the graders, who typically move alongside each moving carcass. Additional hardware improvements would undoubtedly lead to higher cutability prediction accuracy than evidenced during this study.

Implications

Application of USDA yield grade standards, when augmented utilizing video image analysis estimates of longissimus muscle area coupled with USDA on-line grader estimates of adjusted preliminary yield grades, increased grade placement accuracy and improved predictive capability because yield grades were assigned to the nearest 0.1 of a grade. Instrument technology for use in augmentation of USDA yield grade application seems to be valuable for increasing the accuracy and objectivity in commercial application. Further improvements to the augmentation touch panel grading display evaluated in this study are needed if higher accuracy levels are to be achieved.

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